DISCUSSION[1]

"Assessment of Methods for Measuring Embeddedness: Application to Sedimentation in Flow Regulated Streams" by Kelly M. Sennatt, Nira L. Salant, Carl E. Renshaw, and Francis J. Magilligan[2]

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Sennatt *et al.* (2006) expands the science of assessing the effects of flow regulation on stream sedimentation and streambed conditions by combining sediment transport modeling with in-channel assessments of stream condition. They also further science by comparing five commonly used methods for measuring embeddedness and their ability to identify changes in streambed condition. We would like to specifically comment on their application and validation of the embeddeness methods and the selection of one as superior to the others. In our opinion, the conclusion that "the USEPA method most effectively captures the expected impact of flow regulation on embeddedness" and that it, by inference, "may be best able to accurately represent sediment dynamics" overstates the findings of the supporting data.

Embeddedness is a seemingly simple concept regarding the degree of streambed sedimentation. Waters (1995) defines it as the percent saturation of interstitial spaces. As Sennatt *et al.* (2006) point out, numerous studies have correlated the concept of high embeddedness with degraded benthic habitat and a decline in macroinvertebrates. However, measurement of embeddedness in the field has always been problematic (Sylte and Fischenich, 2002). Validated standard methods are lacking and there is no common precise definition of embeddedness.

While embeddeness is generally defined as the "degree to which fine sediments surround coarse substrates on the surface of streambeds" (Sylte and Fischenich, 2002), most measurement techniques measure embeddedness as the depth of fines surrounding larger substrate while visual techniques tend to estimate the percentage of the streambed surface covered by fines. To further complicate the matter, the weighted Burns Quantitative (BSK) Method, combines an estimate of surface coverage with a measurement of embeddedness depth. Thus, visual and measurement-based techniques evaluate embeddedness by related, but different aspects of information on substrate composition. McHugh and Budy (2005) found that visual estimates (Platts/Bain) are typically greater than measurement-based values (weighted BSK) at relatively high levels of embeddedness. They attribute the lack of a 1:1 relationship between visual and measurement-based techniques on fundamental differences in what is measured (surface area *vs* depth of fines).

Embeddedness remains a common monitoring technique in much of the country. In a review of embeddedness use by states from 1997 through 2001, Sylte (2002) found that 16 states use some form of the technique. Contrary to the statement by Sennatt *et al.* (2006), however, embeddedness is no longer routinely used by the USDA Forest Service to characterize streambed conditions and has been largely replaced by more quantitative techniques, such as pebble counts. While embeddedness was widely used by the Forest Service in the late 1980s and early 1990s, internal agency gray literature studies (summarized by Sylte, 2002) offer strong evidence for why embeddedness has been largely dis-

continued as a monitoring tool. In addition, Sylte (2002) raised awareness of a fundamental flaw discovered in the measured embeddedness method, whereby embeddedness computations could indicate a decrease in embeddedness when actual embeddeness has increased. Today, two of the Forest Service's major aquatic monitoring initiatives, the Pacific Northwest Forest Plan Aquatic Resource and Monitoring Program (AREMP) (Reeves *et al.*, 2003) and the PacFish/Infish Biological Opinion Effectiveness Monitoring Program (PIBO) (Kershner *et al.*, 2004) exclude embeddedness as a monitoring parameter. Additionally, the ability of embeddedness to detect changes in land use has been questioned (Potyondy, 1993).

Based on our experience, we found it therefore unusual that Sennatt *et al.* (2006) and a companion paper by Salant *et al.* (2006) studying changes to bed mobility and bed composition under altered flow regimes in the same river systems, selected embeddedness to quantity bed composition even though they also collected data on surface grain-size distributions using Wolman pebble counts. In our opinion, a more scientifically substantive and robust defense of the findings and "ground truthing" could have been provided by using the pebble count data not only to support the findings of sediment transport modeling in the Salant *et al.* (2006) study, but also to evaluate the accuracy of the five embeddedness methods presented in this paper.

In brief, we find scant evidence to support selection of the USEPA method as the approach which best reflects the expected change in embeddedness above and below the dam. As discussed in the results, the data in Figures 2 and 3 show considerable scatter in percent embeddedness values derived from the five techniques, typically ranging over 60 percentage points. Although the ANOVA results indicate significant differences in the average values of each method, on both study sites, most methods appear to track changes similarly to the USEPA method, but at different magnitudes. Also of interest, the USEPA method generally tracks in the middle of the range of values derived from the other four methods, but this is no basis for declaring it superior to the others.

The primary justification for selecting the USEPA method over the other seems to be based on Table 3, where the USEPA method upstream values are found to be statistically higher ($p < 0.01$) than downstream values. However, although not as statistically significant, all of the other methods similarly have higher values downstream compared to upstream, demonstrating their ability to also track change in a logical, expected manner. Absent any measure of true bed composition, as might be provided by peb-

ble count data, there appears to be little basis for declaring the USEPA method superior to the others. It is apparent that one of several possible conclusions was chosen to support what was expected, when the results of other methods show essentially the same outcome.

We note that the authors cite previously reported, independently determined changes in bed aggradations and sand fraction based on physically-based techniques to justify their selection, specifically a multifraction sediment transport model and analysis discussed in greater detail by Salant *et al.* (2006). However, Salant *et al.* (2006) in defending their sediment model note that changes in sand fraction predicted by the sediment transport model are consistent with changes in embeddedness upstream and downstream as quantified by the USEPA method. The argument appears to be circular: the USEPA method embeddedness data are used to show that the sediment model works and the sediment model is used to support selection of the USEPA method as the superior measurement technique. Consequently, the conclusion that "Results show that the U.S. Environmental Protection Agency (USEPA) method best reflects the sediment regime on these rivers" should be stated with caveats and extreme caution.

Although we disagree with the overstated and inconclusive findings, this research does have several very laudable points and future research may find these data valuable in advancing the science of embeddedness measurement because several findings directly reinforce other embeddedness research results. The following conclusions could and should be made:

- Embeddedness values differ significantly between methods, suggesting comparisons of results between methods will likely lead to erroneous conclusions without substantive assessments to define true bed conditions, or until embeddedness estimation techniques undergo further investigation and are proven reliable with respect to their ability to predict true condition and/or trend.
- Significant variance exists between methods and research to develop reliable methodology is necessary, if embeddedness is to progress beyond general characterization into a valid stream substrate metric. A statistical assessment of difference between sites *vs* difference between methods may be useful (this finding is also supported by Sylte and Fischenich (2002), Sylte (2002), and McHugh and Budy (2005).
- The Platts/Bain method consistently yielded the lowest absolute values (this finding is also supported by Sylte and Fischenich (2002) and Sylte (2002).

- The two visual embeddedness estimation methods, USGS and USEPA, (primarily surface area based) are more similar than the methods that require measured techniques (a depth metric), implying that visual techniques are estimating differently than measured techniques (supported by McHugh and Budy (2005).
- Although formal statistical testing is necessary, the measurement method BSK-n seems to result in more similar results to the EPA methodology than other methods (this finding is also supported by Sylte and Fischenich (2002) and Sylte (2002).
- The DTE method by the USFWS consistently yields higher values than all other methods. This may be due to the fact that it samples along the edge of the stream rather than within the channel proper, or it may be caused by the way substrates are selected, or how the depth metric is measured.
- There may be some promise in embeddedness measurement because all methods consistently describe the same trend.

In summary, we concur that embeddedness can differentiate regulated from unregulated conditions, as well as differences caused by dam management, at least in a qualitative sense. We are unconvinced that this study showed that any one technique is superior to the others. To make that determination, embeddedness results need to be compared to accepted surface particle-size distribution measurement techniques, such as pebble counts. We encourage the authors to undertake this analysis since they may have these data.

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